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Peri-operative Mortality and Morbidity of Complex Abdominal Aortic Aneurysms Repair in Switzerland: A Swissvasc Report

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WHAT THIS PAPER ADDS

This study shows the relationship between open and endovascular treatment and organ specific complications in complex abdominal aortic aneurysms. In particular, it shows that mortality is mainly caused by renal failure and intestinal ischaemia. In addition, limb ischaemia caused mortality, especially after endovascular repair. Mortality and morbidity rates did not differ significantly between open aneurysm repair and fenestrated/branched endovascular aortic repair in Switzerland. A lack of centralised care for these complex procedures was identified, and an association between hospital volume and hospital mortality was found.

Objective: Complex abdominal aortic aneurysms (cAAA) pose a clinical challenge. The aim of this study was to assess the 30 day mortality and morbidity for open aneurysm repair (OAR) and fenestrated/branched endovascular aortic repair (F/BEVAR), and the effect of hospital volume in patients with asymptomatic cAAA in Switzerland.

Methods: Retrospective, cohort study using data from Switzerland's national registry for vascular surgery, *Swissvasc*, including patients treated from 1 January 2019 to 31 December 2022. All patients with asymptomatic, true, non-infected cAAA were identified. Primary outcome was 30 day mortality and morbidity reported using the Clavien–Dindo classification. Outcomes were compared between OAR and F/BEVAR after propensity score weighting.

Results: Of the 461 patients identified, 333 underwent OAR and 128 underwent F/BEVAR for cAAA. At 30 days, overall mortality rate was 3.3% after OAR and 3.1% after F/BEVAR (p = .76). Propensity scores weighted analysis indicated similar morbidity rates for both approaches: F/BEVAR (OR 0.69, 95% CI 0.45 – 1.05, p = .055); intestinal ischaemia (1.8% after OAR, 3.1% after F/BEVAR, p = .47) and renal failure requiring dialysis (1.5% after OAR, 5.5% after F/BEVAR, p = .024) were associated with highest morbidity and mortality. Treatment specific complications with high morbidity were abdominal compartment syndrome and lower limb compartment syndrome following F/BEVAR. Overall treatment volume was low for most of the hospitals treating cAAA in Switzerland; outliers with increased mortality were identified among low volume hospitals.

Conclusion: Comparable 30 day mortality and morbidity rates were found between OAR and F/BEVAR for cAAA in Switzerland; lack of centralisation was also highlighted. Organ specific complications driving mortality were renal failure, intestinal ischaemia, and limb ischaemia, specifically after F/BEVAR. Treatment in specialised high volume centres,

alongside efforts to reduce peri procedural kidney injury and mesenteric ischaemia, offers potential to lower morbidity and mortality in elective cAAA treatment.

Keywords: Aortic aneurysm, Abdominal/surgery, Complex abdominal aortic aneurysm, Endovascular procedures/mortality, Swissvasc

INTRODUCTION

The 2024 European Society for Vascular Surgery (ESVS) clinical practice guideline on the management of abdominal aorto-iliac artery aneurysms for the first time covers recommendations for the management of patients with complex abdominal aortic aneurysms (cAAA).[1] The cAAA definition includes a group of aneurysms that involve the reno visceral segment but not the thoracic aorta. More specific, cAAA involve short neck infrarenal abdominal aortic aneurysms (AAA), juxtarenal pararenal, and suprarenal AAA, paravisceral AAA, as well as Crawford type IV thoracoabdominal aneurysms.[1] Only 15 – 20% of all AAAs are considered complex.[1] Consequently, specific data on the natural history, including rupture risk and progression, are either lacking or less robust compared with those for non-complex AAAs.[1]

Surgical treatment of cAAA presents greater challenges because of the lack of a healthy infrarenal neck for aortic cross clamping and suturing or endovascular sealing.[1,2] Open aneurysm repair (OAR) has traditionally been the standard of care for patients with cAAA and AAA fit for this invasive treatment. Depending on the extent of the aneurysm, OAR for cAAA requires inter renal, supra renal or even supra celiac aortic cross clamping and sometimes additional revascularisation of the renal arteries is needed. Cross clamping in the reno visceral aorta can cause temporary or permanent renal function decline and cardiac injury owing to increased afterload.[3–5] Endovascular aortic repair for cAAA has rapidly

developed in the past decade, and is widely implemented in many countries.[5] Different solutions to achieve sealing in the reno visceral segment, such as branched and fenestrated grafts (F/BEVAR), as well as the use of standard EVAR with adjuncts such as endo-stapling or parallel grafts, have been proposed.[6]

Besides the anatomical challenges, this complexity in treatment options also imposes challenges in comparisons: One cAAA might be treated with complex OAR requiring supra-mesenteric clamping and renal bypasses, whereas another might be reconstructed with a juxtarenal suture generally requiring only short supra renal clamping. These procedures dramatically differ in their invasiveness, whereas the endovascular alternative for these patients might not always be an exact equivalent. Further, extending from a standard two fenestration FEVAR to a complex four fenestration FEVAR might only pose a moderate increase in morbidity and mortality.[7]

Specific complications related to endovascular treatment include injuries to the reno visceral arteries causing ischaemia, arterial embolisations, peri-procedural limb ischaemia and bridging stentgraft occlusions.[5] Open repairs are generally associated with higher peri procedural mortality and morbidity, whereas endovascular repairs require more frequent reinterventions to ensure efficacy during follow up.[8] Peri-procedural mortality is well documented, and organ specific complications, especially renal failure, has been investigated.[9] Peri-procedural morbidity associated with different complications, however, has not yet been established.

Given the absence of robust evidence on the natural history of patients with cAAA and the inherently higher risk associated with cAAA repair, the current ESVS guidelines recommend taking an individualised approach when determining the indication for repair.[1] The indication

for treatment and the treatment strategy should, therefore, be based on patients' comorbidities, anatomy, and preference. Ideally, an optimal and individualised patient selection for either open repair, endovascular repair, or no repair at all, should reduce the overall morbidity and mortality associated with cAAA.

The aim of the present study was to assess the 30 day morbidity and mortality for OAR and F/BEVAR, as well as the effect of hospital volume in patients with asymptomatic cAAA in Switzerland.

MATERIALS AND METHODS

This register based cohort study includes all patients electively treated for asymptomatic cAAA in Switzerland from 1 January 2019 to 31 December 2022, excepting Crawford type IV aneurysms. This study was conducted according to the principles of the Declaration of Helsinki and reported in adherence to the Strengthening the Reporting of Observational studies in Epidemiology statement.[10] All patients provided written informed consent for data capturing in *Swissvasc*, and the study was approved by the Ethics Board in Zurich: BASEC-ID: 2023-00489.

Data source

Swissvasc, the official registry for vascular procedures of the Swiss Society for Vascular Surgery, hosted by Adjumed Services AG (Zurich), was used for this study. *Swissvasc* has excellent data quality and was recently validated in a VASCUNET audit in March 2023, showing 94.4% internal validity and 99.8% case ascertainment compared with hospital insurance claim data (validation report not yet published).

Data for this study were extracted on 5 April 2023 to identify eligible patients. Patients were treated at 22 different hospitals throughout Switzerland with varying volume. The six hospitals with the highest case volume carried out 68.0% of the total volume for cAAA in Switzerland. For logistic reasons, incomplete data on comorbidities, procedural details, and outcome information were manually checked and completed at these six hospitals only. Thereby, eligibility was verified and follow up information on survival was updated in *Swissvasc* up to the study end date on 31 of July 2023. Information was obtained from local electronic patient records and updated in *Swissvasc* if not yet entered as part of the local routine. Patients with missing outpatient visits after 1 April 2023 (checked in July 2023) were contacted by telephone to schedule a follow up visit and check for re-intervention and survival status.

Patient selection

Swissvasc is based on matrix structure, which is different to other vascular registries that generally have a tree structure. Patients were filtered according to the following six criteria: elective procedure; open surgical or endovascular procedures; aorto-iliac, including the renal segment; true aneurysms; no previous aortic procedure at the relevant vascular segment; and no infection confirmed or suspected. For practical reasons, entries not meeting these criteria were not further checked for erroneous coding that would lead to inclusion if corrected.

Treatment at the renal segment was defined as either OAR needing aortic cross-clamping at least proximal to one main renal artery or endovascular therapy where fenestrations or branches were used for at least one main renal artery (= F/BEVAR). Patients treated with EVAR and adjuncts such as parallel grafts or endo stapling were excluded.

Outcome measures

The primary outcome was mortality and morbidity at 30 days reported by a simplified Clavien–Dindo classification (Table 3).[11] This classification was introduced in 2004 and is frequently used in general and oncological surgery. In short, the Clavien–Dindo classification is an ordinal scale and has six grades (0 = no complications; I = complications requiring pharmacological therapy; II = complications requiring blood transfusion, parenteral nutrition, etc.; III = complications requiring surgical or interventional intervention; IV = life-threatening complication with organ failure; and V = death). Patients can encounter several complications, but the most severe complication defines the final grading. Secondary outcomes included all specific complications available in *Swissvasc* as well as overall mortality during the follow up.

Missing data

Data were assumed to be missing at random and imputed (number of imputed datasets, n = 25) using the multiple imputation by chained equations method implemented in R's mice package.[12] Continuous variables and ordered factor variables were imputed using the predictive mean matching method. Categorical variables were imputed using a polynomial regression. Missing outcome variables "Clavien–Dindo" and "mortality" were not imputed. Imputations were visually inspected using density and summary plots.

Statistical analysis

Propensity score weighting was used to adjust for covariate imbalances between patients treated with OAR and F/BEVAR using R's weightIt package.[13] The covariates were selected according to their clinical relevance and included age, sex, body mass index, smoking status, aneurysm diameter, renal function, New York Heart Association class, coronary artery disease, chronic obstructive pulmonary disease, and hospital volume. Propensity scores were

estimated using a generalised boosted model and an average treatment effect. Balanced weighting was achieved for all variables.

Morbidity was compared between patients treated with OAR and F/BEVAR after propensity score weighting on the imputed dataset using a multivariable ordinal logistic regression model.

The crude secondary end points were presented and compared between treatment groups using chi squared tests. Kaplan–Meier estimators were plotted for both treatment groups and compared using the log-rank test. To assess the relationship between hospital volume and mortality a funnel plot with a 95% confidence band was plotted using a binominal distribution.

Baseline characteristics of the cohort were summarised per treatment group and compared as appropriate: continuous variables were visually inspected for normality and summarised using the median and quartiles (Q1, Q3) if skewed or by mean and standard deviation if a normal distribution was present; factor variables were compared by chi-square test and continuous variables by the Kruskal–Wallis rank test or t-test as appropriate. R Studio version 4.2.3 on MacOS version 12.5.1 was used for all statistical analyses.

RESULTS

Between 1 January 2019 and 31 December 2022, 53 835 procedures were captured in *Swissvasc*. A total of 461 patients were treated for asymptomatic non-infected true abdominal aortic aneurysms that involved the renal segment (cAAA) (Fig. 1). Of these patients, 333 were treated with OAR, whereas 128 patients were treated with F/BEVAR. Patients undergoing F/BEVAR were older (75.0 *vs.* 71.2 years, $p < .001$), and were more likely to have heart

failure compared with OAR patients (New York Heart Association III or IV in 7.4% *vs*. 1.9%, $p = .014$). The length of stay was significantly longer after OAR (9 *vs*. 5 days, $p < .001$), whereas the median operation time did not differ significantly between the two treatment groups (median total duration of 222 minutes+). Details on baseline characteristics and procedural details are presented in Table 1 and Table 2.

Mortality

The crude hospital mortality was available in 456 of the 461 patients and did not differ significantly between OAR (3.1%) and F/BEVAR (3.3%) ($p = .92$). Survival information at 30 days was missing in 47 patients showing a similar picture: 3.3% mortality after F/BEVAR compared with 3.1% after OAR ($p = .76$). Of note, no additional deaths after discharge were reported.

The median follow up was 12.1 months (1.6 – 28.9), with a median follow up Index of 0.83 (Q1, Q3: 0.07, 0.97). The Kaplan–Meier estimator is available in the supplement (Supplementary Figure S1), and shows that the crude survival rates did not differ significantly between patients treated with F/BEVAR or OAR ($p = .90$) (log rank). Survival was 94% (95% CI 91 – 97%) after OAR and 89% (83 – 95%) after F/BEVAR at 1 year.

Hospital volume

The overall hospital volume and volume per treatment method for the entire study period (four years) are presented in Table 2. A total of 22 hospitals carried out elective surgery for cAAA over the observed four years. The total case volume per clinic was significantly lower for endovascular treatment with a median of two procedures (Q1, Q3: 1, 5) compared with 11 (1, 20) for OAR ($p = .023$). Open surgery was carried out in 17 hospitals, whereas F/BEVAR was carried out in 21 hospitals. Only three hospitals can be identified as high volume centres,

with an annual volume of 10 cAAA cases or more (F/BEVAR and/or OAR). Most of the hospitals treating cAAA in Switzerland have a low annual volume: 14 hospitals carried out fewer than five complex elective open repairs and 15 hospitals carried out fewer than five elective F/BEVAR for cAAA.

A funnel plot for total hospital volume in the overall study period and hospital mortality is presented in Figure 2. The plot shows the Swiss average survival at 96.7% survival (or 3.3% mortality), with a blue dashed line and a corresponding 95% confidence band reflecting the expected wider scattering of mortality with lower hospital volume. The plot indicates that five hospitals were outside the expected hospital mortality. One high volume centre had significantly lower mortality than the Swiss average at 0%; two low volume hospitals (mortality at 50.0% and 16.7%) and two medium volume (mortality at 9.5% and 10.0%) had significantly higher rates than expected.

Thirty day complications

Swissvasc allows coding of multiple complications per patient and an overall reporting of morbidity using the Clavien–Dindo classification.[11] Complications are stratified by treatment and presented in Table 3. All specific complications by organ system and the associated morbidity according to the Clavien–Dindo classification are further presented in Figure 3.

Intestinal ischaemia. The complication causing the highest morbidity and mortality was intestinal ischaemia, observed in 2.2% of all patients. Specifically, it occurred in 1.8% of patients treated with OAR (n = 5) and in 3.1% after F/BEVAR (n = 4) (p = .47). The associated morbidity was severe, with four fatalities and an additional five patients requiring intensive care treatment (grade IV).

Renal failure. Renal failure is a comparably high morbidity had severe postoperative renal failure requiring dialysis. It was observed in 2.6% of patients and significantly more often after F/BEVAR (5.5% *vs*.1.5% after OAR, $p = .024$). Four of the 12 patients requiring dialysis (33.3%) died within 30 days and another two patients had life threatening organ failure treated in the intensive care unit (grade IV). Of note, baseline estimated glomerular filtration rate (eGFR) was missing in 19.3% of all patients; however, a non-significant tendency towards lower baseline eGFR according to the Kidney Disease Improving Global Outcomes class in F/BEVAR was observed compared with OAR ($p = .10$).

Respiratory failure. Pneumonia occurred in 4.2% of patients after OAR compared with 1.6% after F/BEVAR ($p = .26$). Respiratory failure requiring intubation was observed in 1.2% of patients after OAR and 1.6% after F/BEVAR ($p = .67$). Most of the patients with pneumonia (12 out of 16) did not require intensive care treatment. If respiratory failure occurred, however, the mortality rate was high, with two fatalities among six patients. Abdominal compartment syndrome was seen in one patient after OAR (0.3%) and in two patients after F/BEVAR (1.6%) ($p = .19$). The associated morbidity was high, with two patients succumbing and the remaining patient experiencing organ failure necessitating intensive care treatment.

Paraplegia. Transient paraplegia was observed in one patient after OAR (0.3%) ($p = .98$). The associated morbidity, as classified by the Clavien–Dindo classification, was moderate (grade III) for this patient, as no surgical revision was required nor did the patient experience life threatening organ failure. Permanent paraplegia was not observed in both subgroups.

Other complications. A prolonged delirium lasting over three days was the most frequently reported complication. In most patients, this was only associated with Clavien–Dindo grade II

complications, meaning that neither organ failure, nor intensive care or death, were recorded. Of note, lower limb compartment syndrome was seen in four patients (3.1%) after F/BEVAR but not after OAR (p = .006). In these patients, two deaths were observed.

Morbidity by treatment

The Clavien–Dindo grade was available for 414 of the 461 patients (89.8%), and did not differ between the groups in an unadjusted comparison (p = .78). Information on morbidity was missing predominantly in smaller hospital (missing: n = 21 in low volume, n = 26 in medium volume), whereas data were complete for high volume hospitals (Supplementary Table S1).

Mild complications (grade I) requiring pharmacological treatment were reported in 7.2% of patients. More relevant complications with the need for blood transfusion or antibiotics (grade II) were reported in 17.9% of the patients. Severe complications requiring any type of intervention or reintervention (grade III) were seen in 9.7% of the patients. Life threatening complications (grade IV) were seen in 3.4% of patients. Finally, 15 patients died within 30 days after complex abdominal aortic surgery (3.6%).

The multivariable propensity score weighted analysis on the complication grading (Clavien–Dindo) is presented in Figure 4. Treatment modality was not significantly associated with complication rates at 30 days (OR 0.69, 95% CI 0.45 – 1.05, p = .083) for F/BEVAR. Female sex (OR 1.81, 95% CI 1.04 – 3.17, p = .037) and larger aneurysm diameter per cm increase (OR 1.28, 95% CI 1.02 – 1.63, p = .036) were associated with more, or more severe complications. Further, there was a tendency towards higher complications in active or former smokers, with decreasing renal function as well as for increasing New York Heart Association class. Finally, chronic obstructive pulmonary disease (COPD) without medication was

associated with a doubled risk for complication compared with patients without COPD (OR 2.07, 95% CI 1.11 – 3.87, p = .022). Hospital volume was not included in the adjusted analysis owing to the uneven distribution of missing data in the outcome variable (Supplementary Table S1).

DISCUSSION

Swissvasc has an excellent coverage for complex aortic procedures. The present study, therefore, provides real world epidemiological data on a homogeneous cohort of patients with AAA involving the renal segment in Switzerland between 2019 and 2022. All patients were asymptomatic, had true and non-infected cAAA, had not undergone previous aortic surgery at this segment, and all of them received elective treatment. Imbalances between patients receiving F/BEVAR and OAR were addressed by propensity score weighting and exclusion of Crawford type IV aneurysms. Therefore, the present study provides a comprehensive picture of the 30 day mortality and morbidity associated with elective cAAA treatment in Switzerland. It reveals a significant burden of morbidity and mortality associated with elective surgery for cAAA in Switzerland and highlights a concerning lack of centralisation of care.

The mortality rate at 30 days was 3.6% after OAR and 3.4% after F/BEVAR, and did not differ significantly between the two methods (p = .76). These figures are in line with data published in a meta-analysis in 2019 reporting a post-operative mortality following OAR of 4.2% (95% CI 2.9 – 5.7) and 3.3% (95% CI 2.0 – 5.0) following FEVAR.[14] Recently, the UK-COMPASS cohort study presented an overall peri procedural mortality rate for cAAA of 2.9%. The peri-operative mortality for OAR was 4.5%, whereas it was 2.2% for FEVAR. For patients treated with standard EVAR, the mortality was lower at 1.2%. *Swissvasc* does not capture neck length. Therefore, patients receiving standard EVAR for short neck AAA cannot be identified. It is noteworthy that the proportion of cAAA of all AAA in the UK-COMPASS was 30.7%, whereas it was only 19.7% in *Swissvasc*. When excluding the EVAR subgroup from the UK-COMPASS cohort, the proportion of cAAA on the overall AAA population is similar to that captured in *Swissvasc*. In addition to the UK-COMPASS data, recently published data from a multicentre study of high volume centres in Europe, showed 30 day mortality rate of 4.1% for F/BEVAR and 5.5% for OAR (p = .80).[5] In contrast, in a propensity

matched cohort, Tinelli *et al*.[8] recently reported a 2.9% mortality rate after OAR and a 3.9% after F/BEVAR for treatment of cAAA at two high volume centres.[8]

The current ESVS clinical practice guideline for the treatment of aneurysms of the abdominal aorto-iliac artery emphasises the difficulties in comparing outcomes between OAR and F/BEVAR in patients with cAAA.[1] Because of the complexity and variety of cAAA, comparisons remain difficult even after stratification for anatomical parameters and surgical risk. Therefore, it may be more useful to evaluate and compare the overall outcomes of cAAA treatment within a population or at a specific centre rather than comparing treatment modalities. For Switzerland, this study shows that overall mortality in the treatment of cAAA is within the expected range. Some low and medium volume hospitals have mortality rates that deviate negatively from the expected 95% confidence band. The lack of centralisation of cAAA treatment in specialised high volume centres that offer both open and endovascular repairs is clearly presented in Figure 2, as recommended in the ESVS guidelines.[1] It should be noted that the *Swissvasc* filtering to obtain this homogeneous cohort deselected a relevant proportion of complex abdominal aortic procedures, e.g., treatment of dissections, symptomatic patients, cuffs, and open conversions for failed endografts. The actual case volume for complex aortic procedures on the reno-visceral aorta is therefore probably higher in most hospitals. The association between hospital volume and treatment outcomes, however, is well documented for aortic surgery.[15] Regulations for centralised care of aortic surgery and complex aortic surgery in particular are still lacking in Switzerland.[16] As the Swiss rescue chain enables fast and safe transfers between hospitals, the argument in favour of decentralised elective aortic surgery for better treatment of rupture cases is refuted.[17,18]
The complications associated with the highest mortality rates in the present study were abdominal compartment syndrome with a 50.0% mortality rate, lower limb compartment syndrome (50.0%), intestinal ischaemia (40.0%), as well as stroke, renal failure requiring

dialysis, and respiratory failure requiring intubation, each with a mortality rate of 33.3%. In absolute numbers, renal failure requiring dialysis (2.6%) and intestinal ischaemia (2.2%) were the most relevant complications causing mortality. Identification of specific complications that are associated with high morbidity or even mortality offers the possibility to enhance complication management and thereby decrease the rate of failures in rescue.

Acute kidney injury (AKI) has previously been identified as one of the most relevant complications after cAAA repair.[6,9] Zlatanovic *et al*.[9] described significantly higher mortality in patients with AKI after cAAA repair compared with patients without AKI for both OAR and F/BEVAR.Klicken oder tippen Sie hier, um Text einzugeben. In a European multicentre study, they reported AKI in 2.3% after OAR and 2.6% after F/BEVAR. These rates are comparable to our overall rate of 2.6%. A significantly lower rate of renal function loss, however, was identified after OAR (1.5%) compared with F/BEVAR (5.5%) (p = .024). In more than 50% of their OAR cohort, either a single renal bypass (34.5%) or bypasses to both kidneys (18%) were carried out. As expected, AKI was observed more frequently after renal bypasses, especially after bypasses to both kidneys. Our registry data do not allow us to present this information, and the most plausible explanation could be a more limited extent of repair in our cohort with a lower proportion of patients receiving bypasses. For endovascular treatment, the observed rate of 5.5% in our cohort needs further elaboration. There was a tendency towards worse eGFR at baseline in patients receiving F/BEVAR in the present cohort. Specifically, 10.4% of the F/BEVAR patients had moderately to severely decreased renal function, and 3.4% had severely decreased eGFR at baseline; these numbers were 5.5% and 3.1%, respectively, for OAR patients. This might partially explain the high rate of renal failures in this study. Alternative explanations include renal ischaemia caused by target artery injury and extensive use of contrast medium during F/BEVAR. Both factors might be associated to case volume that seems to be low in Switzerland, especially for complex

endovascular therapy. The results for both OAR and F/BEVAR could also differ to the results presented by Zlatanovic *et al*.,[9] owing to differences in baseline renal function or in peri-operative management of renal ischaemia during OAR. In any case, both studies demonstrate the importance of this complication and the efforts needed to limit renal injury to reduce morbidity and mortality.

Other specific complications included intestinal ischaemia, seen in 2.2% of all patients without significant differences between OAR (1.8%) and F/BEVAR (3.1%). These rates are similar to the 1.5% for OAR and 1.3% for F/BEVAR % (both colon ischaemia only) reported by Zlatanovic *et al*.[9] from high volume European centres.Klicken oder tippen Sie hier, um Text einzugeben. Historic data from the national Vascular Quality Initiative revealed an incidence of intestinal ischaemia of 2.7% among over 3 000 patients treated with F/BEVAR between 2012 and 2017 in the USA and Canada. The considerably high morbidity and mortality associated with intestinal ischaemia, as demonstrated in this study, underscores the importance of prompt and thorough diagnostic evaluation in cases of suspected mesenteric perfusion issues with prompt treatment.

Lower limb compartment syndrome was only seen after F/BEVAR but with a rate of 3.1% in the F/BEVAR cohort, and a mortality rate of 50.0% seems to be an astonishingly relevant problem. The underlying mechanism is likely prolonged peri-operative malperfusion caused by large and occlusive sheaths in the groin and consecutive reperfusion injury. Presumably, it is not the compartment syndrome itself that drives mortality but the underlying difficulties and complications that occurred at first and led to the prolonged limb ischaemia. Of note, procedures in the four patients with compartment syndromes had a median duration of 445 minutes where it was only 214 minutes in the overall F/BEVAR group. Nevertheless, a raised awareness of the potential effect of limb ischaemia in endovascular interventions, and a

strategy to reduce sheath size and procedural duration whenever possible, could improve F/BEVAR outcomes.

To quantify the morbidity of specific complications and facilitate comparison between two fundamentally different treatment approaches, well established Clavien–Dindo classification was used, which is commonly used in abdominal and oncological surgery but less so in vascular surgery.[11] The overall hospital complication rate after treatment of cAAA was 41.8%, with a tendency towards lower morbidity in patients treated with F/BEVAR, although this did not reach statistical significance (OR 0.69, 95% CI 0.45 – 1.05, p = .055). While no statistically significant difference was observed in overall morbidity between treatment modalities, the pattern of complications differed substantially between OAR and F/BEVAR as previously discussed. The adjusted analysis on overall 30 day morbidity further revealed that female sex, larger aneurysm diameter, and COPD were associated with more severe complications. The adjusted morbidity was almost twice as high in women compared with men (OR 1.81, 95% CI 1.04 – 3.17, p = .037). Sex disparities with adverse outcomes in women following the treatment of standard AAA have been previously identified.[20] Specifically in standard EVAR for AAA, women had elevated rates of cardiac complications, arterial injuries, and arterial embolisations. It is likely that these complications might also cause increased morbidity and mortality in the treatment of women with cAAA. An association of increasing aneurysm diameter and COPD with peri-operative mortality, as well as with impaired long term survival, has previously been demonstrated for AAA.[21–24] It seems plausible that both factors play a similar role in patients with cAAA. Because of the lack of reporting of the Clavien–Dindo grading in low volume hospitals, the association between hospital volume on morbidity could not be assessed. It is worth noting that only long term data can provide an overall picture on morbidity and mortality of the two treatment approaches, especially given that reintervention rates and late complications are known and

higher for F/BEVAR.[25] Therefore, continued follow up after cAAA treatment is mandatory. Attempts should be made to record reinterventions and late complications as well as information on overall survival in clinical databases and registers.

Limitations

Several limitations should be considered when interpreting the results. The study's retrospective nature might inherently introduce bias. Specifically for this setting, data were only double checked and completed for missingness in the six largest hospitals but not in the smaller hospitals that treated approximately one third of patients. Nevertheless, recent evidence of complete case ascertainment in *Swissvasc* supports the identification of a real world cohort, which is a strength compared with highly selected cohorts participating in most prospective studies.[26] *Swissvasc* allowed the identification of a homogeneous cohort. Some specific anatomical parameters, such as access vessel diameters, thrombus burden, and previous abdominal surgery, as well as general fitness and frailty, are not captured. Hence, some residual confounding factors might have influenced the present findings.

Furthermore, peri procedural outcomes are presented only for treatments that are associated with relevant mid and long term consequences.[5,19] The provided information must, therefore, be put into perspective of durability of repair and the need for re-interventions, as well as the overall survival and burden of treatment in the follow up in patients with cAAA.

Lastly, there is a risk of a type II error owing to the limited sample size. Larger studies with a focus on morbidity may uncover clinically relevant differences. Future research could also explore specific aspects, such as the effect of different endograft designs, the learning curve associated with F/BEVAR, and the cost effectiveness of each approach, especially in the light of reinterventions. Moreover, investigations into patient reported outcomes and quality of life

after treatment could provide a more comprehensive understanding of the holistic effect of cAAA repair.

Conclusion

Comparable 30 day mortality rates were found between elective OAR and F/BEVAR for cAAA in Switzerland, consistent with published data. A lack of centralisation was also revealed and low volume hospitals with high mortality rates were identified. Organ specific complications driving mortality included renal failure and intestinal ischaemia, with limb ischaemia specifically seen after F/BEVAR. Treatment of cAAA in specialised high volume centres, coupled with initiatives aimed at reducing peri procedural kidney injury and mesenteric ischaemia, holds promise for further reducing morbidity and mortality associated with managing cAAA patients.

DATA AVAILABILITY

Data are not publicly available because of Swiss data protection law, as they contain information that could compromise the privacy of research participants. The data supporting this study's findings are available on request from the Thomas Lattmann with a respective ethical approval (https://swissethics.ch/basec).

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CONFLICT OF INTEREST

None.

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Table 1. baseline characteristics (*n* = 461).

Characteristics	**Open surgery (*n* = 333)**	**F/BEVAR (*n* = 128)**	**Overall (*n* = 461)**	***p* value**
Age – y	71.2 ± 7.1	75.0 ± 6.6	72.2 ± 7.2	<.001
Male sex	279 (83.8)	104 (81.2)	383 (83.1)	.52
BMI – kg/m^2	26.6 ± 4.2	26.7 ± 5.4	26.7 ± 4.6	.88
Missing	74	6	80	
Arterial hypertension				.066
Yes (controlled)	197 (75.5)	98 (79.7)	295 (76.8)	
Yes (uncontrolled)	32 (12.3)	6 (4.9)	38 (9.9)	
Missing	72	5	77	
Tobacco				.36
Active smoker	140 (53.2)	57 (47.1)	197 (51.3)	
Previous smoker (>3 mo cessation)	81 (30.8)	38 (31.4)	119 (31.0)	
Missing	70	7	77	
Kidney function, KDIGO				.10
G1 eGFR >90	42 (16.4)	9 (7.8)	51 (13.7)	
G2 eGFR 60–89	151 (59.0)	69 (59.5)	220 (59.1)	
G3a eGFR 45–59	41 (16.0)	22 (19.0)	63 (16.9)	
G3b eGFR 30–44	14 (5.5)	12 (10.3)	26 (7.0)	
G4-5 eGFR <30	8 (3.1)	4 (3.4)	12 (3.2)	
Missing	77	12	89	
Heart failure				.014
NYHA I	31 (11.9)	16 (13.1)	47 (12.3)	

NYHA II	24 (9.2)	18 (14.8)	42 (11.0)	
NYHA III-IV	5 (1.9)	9 (7.4)	14 (3.7)	
Missing	73	6	79	
COPD				.091
COPD without medication	37 (14.2)	17 (13.8)	54 (14.1)	
COPD with medication including O^2	31 (11.9)	25 (20.3)	56 (14.6)	
Missing	73	5	78	
Peripheral artery disease				.43
Fontaine I	45 (17.2)	26 (21.8)	71 (18.7)	
Fontaine II	30 (11.5)	9 (7.6)	39 (10.3)	
Fontaine III	2 (0.8)	0 (0.0)	2 (0.5)	
Missing	72	9	81	
Diabetes mellitus				.66
Oral antidiabetics	29 (11.1)	17 (13.8)	46 (11.9)	
Insulin	7 (2.7)	4 (3.3)	11 (2.9)	
Missing	71	5	76	
Aneurysm diameter – mm	57 (54, 64)	58 (55, 62)	57 (55, 64)	.27
Missing	33	7	40	

Data were complete if not stated explicitly. Data are presented as *n*, mean ± standard deviation or *n* (%). BMI = body mass index; COPD = chronic obstructive pulmonary disease. eGFR = estimated glomerular filtration rate in ml/min/1.73m^2; F/BEVAR = fenestrated or branched endovascular aortic repair; KDIGO = Kidney Disease: Improving Global Outcomes; NYHA = New York heart association.

Table 2. Details of procedures and hospital volume (*n* = 461).

Anatomy and procedural details	**Open surgery (*n* = 333)**	**F/BEVAR (*n* = 128)**	**Overall (*n* = 461)**	***p* value**
Length of hospital stay – d	9 (7, 13)	5 (4, 8)	8 (6, 12)	<.001
Operation duration – min	227 (180, 289)	214 (154, 270)	222 (176, 287)	.071
Missing	2	0	2	
Iliac femoral outflow intervention				.089
Same approach	14 (5.0)	11 (10.3)	25 (6.5)	
Hybrid approach	3 (1.1)	0 (0.0)	3 (0.8)	
Missing	53	21	74	
Annual volume (number of hospitals)	21	17	22	NA
Low volume (<5 cases)	14	15	13	
Medium volume (≥5 to <10 cases)	5	2	6	
High volume (≥10 cases)	2	0	3	
Median hospital volume (2019–2022)	11 (1, 20)	2 (1, 5)	14 (3, 27)	.020
Year of treatment				.003
2019	81 (24.3)	16 (12.5)	97 (21.0)	
2020	77 (23.1)	28 (21.9)	105 (22.8)	
2021	69 (20.7)	45 (35.2)	114 (24.7)	
2022	106 (31.8)	39 (30.5)	145 (31.5)	

Continuous variables are summarised by median and quartiles (Q1, Q3). Counts are presented with percentages in brackets. The median hospital volume describes the number of procedures performed per hospital that offered the treatment (open aneurysm repair or F/BEVAR) in the period between 2019 and 2022. F/BEVAR = fenestrated or branched endovascular aortic repair; NA = not available.

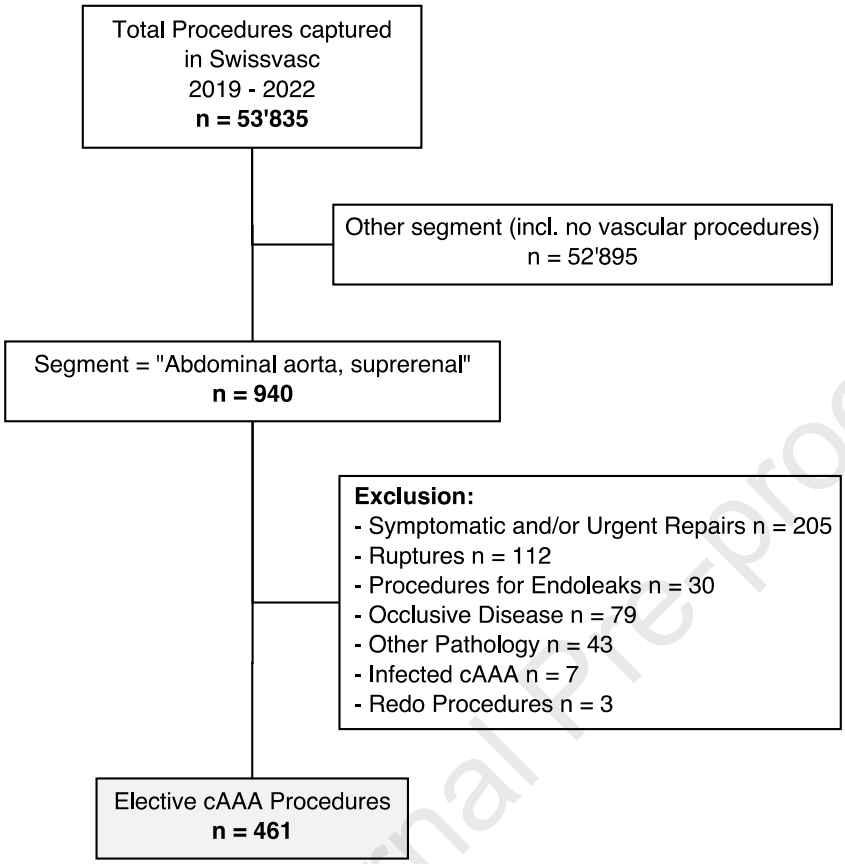
Table 3. **Post-operative complications at 30 days (*n* = 461).**

Postoperative complications (30 days)	**Open surgery (*n* = 333)**	**F/BEVAR (*n* = 128)**	**Overall (*n* = 461)**	***p* value**
Clavien–Dindo grade				.78
0, None	171 (58.2)	70 (58.3)	241 (58.2)	
I, Basic pharmacological therapy needed	19 (6.5)	11 (9.2)	30 (7.2)	
II, Blood transfusions, antibiotics, parenteral nutrition, etc.	63 (21.4)	11 (9.2)	74 (17.9)	
III, Endoscopic, radiologic, or surgical intervention needed	19 (6.5)	21 (17.5)	40 (9.7)	
IV, Life threatening organ failure	11 (3.7)	3 (2.5)	14 (3.4)	
V, Death	11 (3.7)	4 (3.3)	15 (3.6)	
Missing	39	8	47	
Cardiovascular				
ST elevation myocardial infarction	5 (1.5)	1 (0.8)	6 (1.3)	.98
Intestinal ischaemia	6 (1.8)	4 (3.1)	10 (2.2)	.47
Arterial embolisation	3 (0.9)	5 (3.9)	8 (1.7)	.041
Deep vein thrombosis	1 (0.3)	0 (0)	1 (0.2)	.98
Pulmonary embolism	1 (0.3)	0 (0)	1 (0.2)	.98
Infection				
Local wound infection	4 (1.2)	0 (0)	4 (0.9)	.58
Deep wound infection	0 (0)	2 (1.6)	2 (0.4)	.077
Infected synthetic vascular graft	1 (0.3)	0 (0)	1 (0.2)	.98
Sepsis/bacteriaemia	4 (1.2)	4 (3.1)	8 (1.7)	.23
Urinary tract infection	5 (1.5)	4 (3.1)	9 (2.0)	.27

Respiratory				
Pneumonia	14 (4.2)	2 (1.6)	16 (3.5)	.26
Pleura effusion requiring drainage	0 (0)	1 (0.8)	1 (0.2)	.28
Respiratory failure with intubation	4 (1.2)	2 (1.6)	6 (1.3)	.67
Abdominal				
Ileus requiring surgery	1 (0.3)	1 (0.8)	2 (0.4)	.48
Abdominal compartment with decompression	1 (0.3)	2 (1.6)	3 (0.7)	.19
Gastrointestinal bleeding	0 (0)	2 (1.6)	2 (0.4)	.077
Renal failure requiring dialysis	5 (1.5)	7 (5.5)	12 (2.6)	.024
Neurological				
Stroke	3 (0.9)	0 (0)	3 (0.7)	.56
Paraplegia	0 (0)	0 (0)	0 (0)	NA
Transient paraplegia	1 (0.3)	0 (0)	1 (0.2)	.98
Delirium >3 d	8 (2.4)	9 (7.0)	17 (3.7)	.026
Bleeding and others				
Lower limb compartment syndrome	0 (0)	4 (3.1)	4 (0.9)	.006
Lymphocele	0 (0)	2 (1.6)	2 (0.4)	.077
Post-operative bleeding	3 (0.9)	4 (3.1)	7 (1.5)	.10
Bleeding requiring surgical treatment	3 (0.9)	1 (0.8)	4 (0.9)	.98
Haemorrhagic shock	6 (1.8)	2 (1.6)	8 (1.7)	.98

Data are presented as *n* (%). The Clavien–Dindo Classification was used to rate severity of complications at discharge.[11] Levels of the variable were merged, i.e., no subcategories per level. F/BEVAR = fenestrated or branched endovascular aortic repair; NA = not available.

Figure 1. Patient selection from the *Swissvasc* registry.



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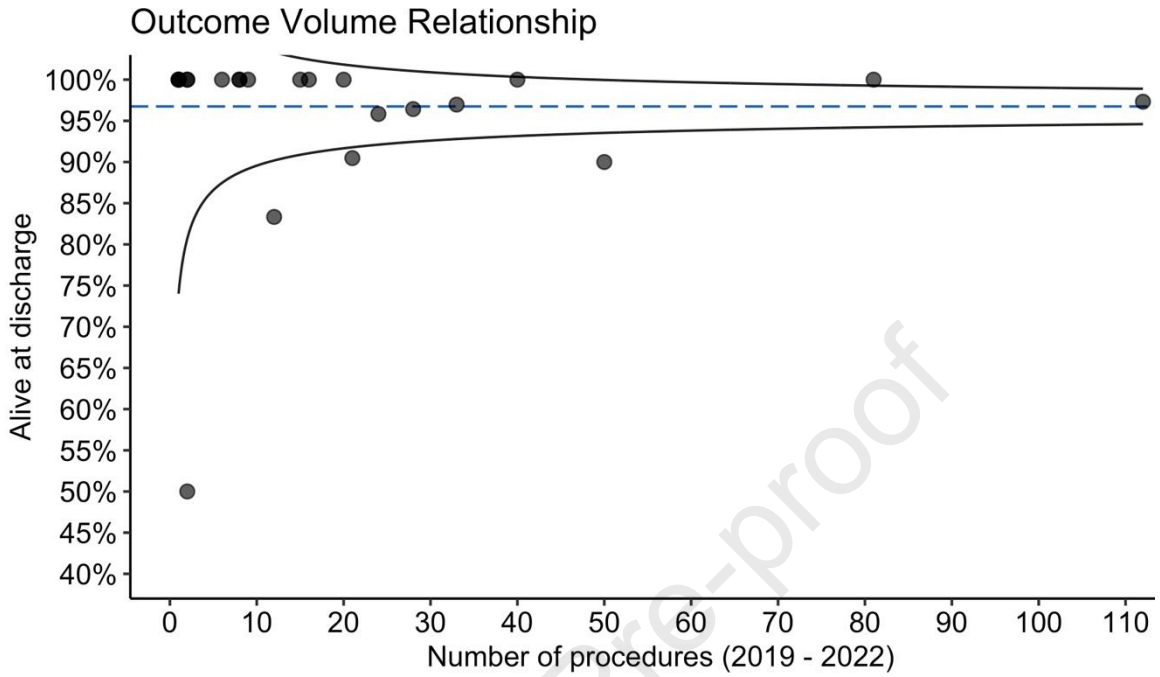
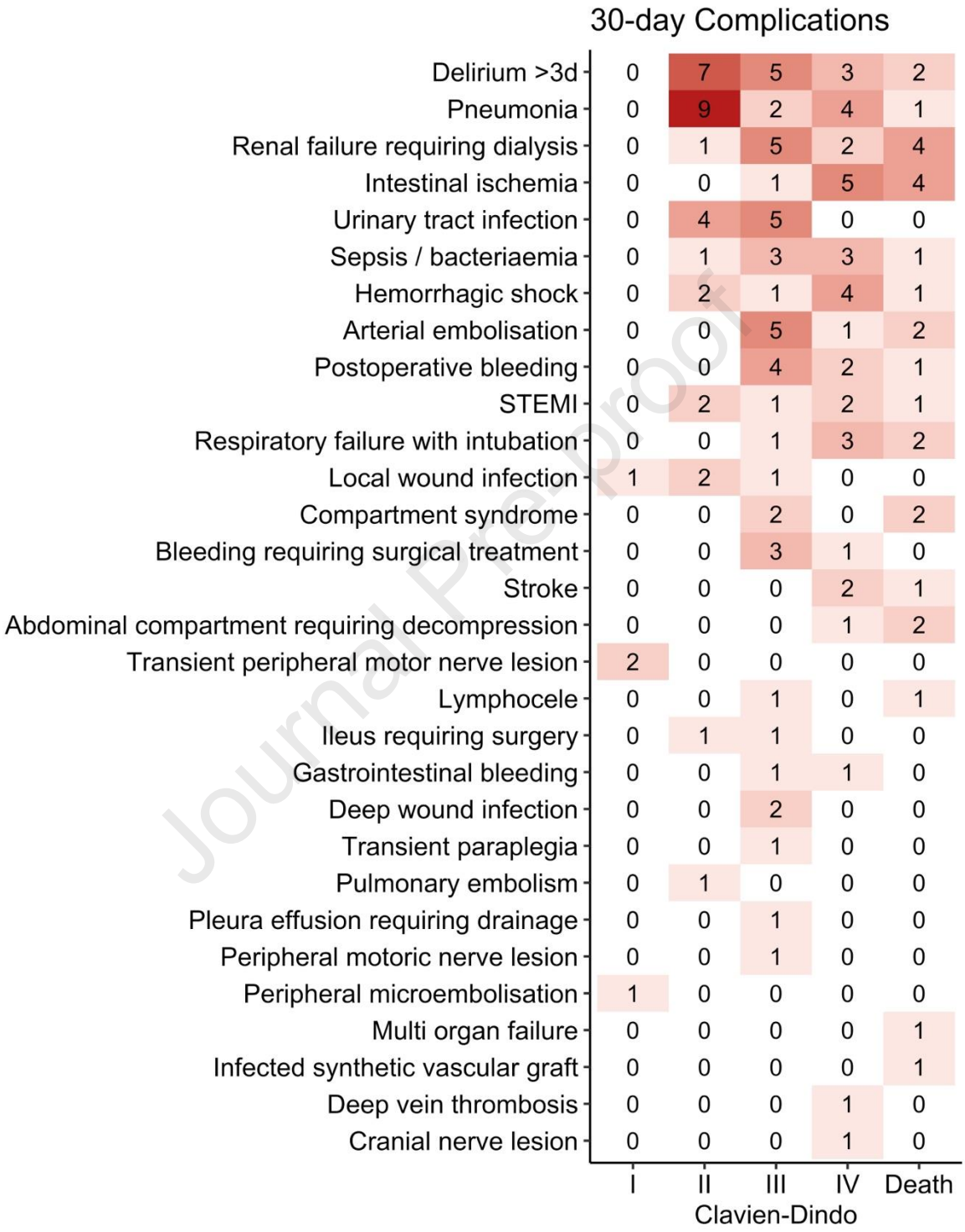
cAAA = complex abdominal aortic aneurysm.

Figure 2. Hospital mortality and volume.



Total hospital volume for open and endovascular repair for juxtarenal and suprarenal abdominal aortic aneurysms between 2019 and 2022 and hospital mortality. Information on mortality was missing in five patients.
The blue dashed line shows the mean mortality rate in Switzerland at 3.3% (benchmark). The black lines indicate the 95% "control limit" for the benchmark, which is based on a normal approximation to the binomial distribution.

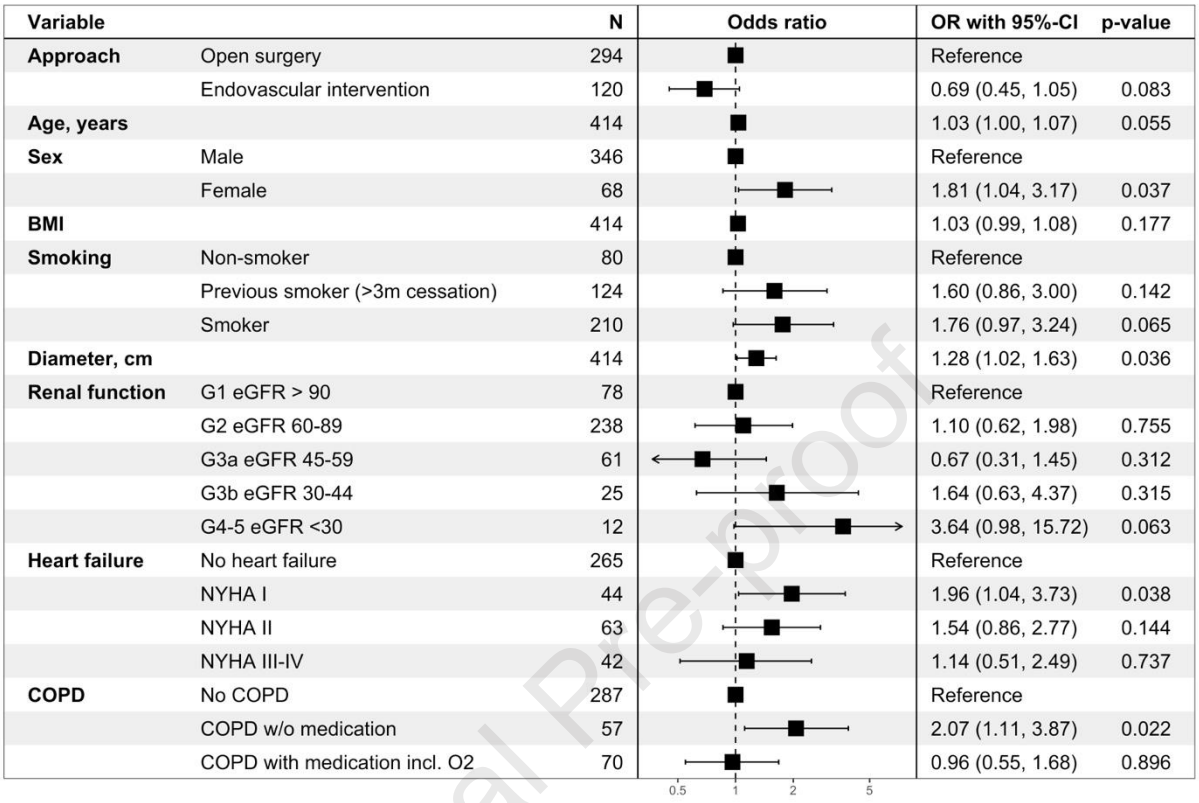
Figure 3. Complications at 30 days.



Heatmap showing all post-operative complications up to 30 days. Coding of multiple complications per patient was possible. Complications are plotted against the overall severity of all complication in the respective patient using a modified Clavien–Dindo classification.[11]

The saturation of the colouring increases with the count. STEMI = ST-elevation myocardial infarction.

Figure 4. Complications at 30 days.



Variable		N	Odds ratio	OR with 95%-CI	p-value
Approach	Open surgery	294		Reference	
	Endovascular intervention	120		0.69 (0.45, 1.05)	0.083
Age, years		414		1.03 (1.00, 1.07)	0.055
Sex	Male	346		Reference	
	Female	68		1.81 (1.04, 3.17)	0.037
BMI		414		1.03 (0.99, 1.08)	0.177
Smoking	Non-smoker	80		Reference	
	Previous smoker (>3m cessation)	124		1.60 (0.86, 3.00)	0.142
	Smoker	210		1.76 (0.97, 3.24)	0.065
Diameter, cm		414		1.28 (1.02, 1.63)	0.036
Renal function	G1 eGFR > 90	78		Reference	
	G2 eGFR 60-89	238		1.10 (0.62, 1.98)	0.755
	G3a eGFR 45-59	61		0.67 (0.31, 1.45)	0.312
	G3b eGFR 30-44	25		1.64 (0.63, 4.37)	0.315
	G4-5 eGFR <30	12		3.64 (0.98, 15.72)	0.063
Heart failure	No heart failure	265		Reference	
	NYHA I	44		1.96 (1.04, 3.73)	0.038
	NYHA II	63		1.54 (0.86, 2.77)	0.144
	NYHA III-IV	42		1.14 (0.51, 2.49)	0.737
COPD	No COPD	287		Reference	
	COPD w/o medication	57		2.07 (1.11, 3.87)	0.022
	COPD with medication incl. O2	70		0.96 (0.55, 1.68)	0.896

Multivariable ordinal logistic regression model with a modified Clavien–Dindo classification for morbidity as an outcome variable (Figure 3 and supplementary Table S1). Complete case analysis after imputation of missing covariable data according to Table 1.
Reading example: The odds for increased morbidity, i.e. one level higher in Clavien–Dindo class) after open surgery is 0.69 (95% CI 0.45 – 1.05) times the rate it is after an open surgery (= lower).
Null deviance: 571; residual deviance: 537.
BMI = body mass index; CI = confidence interval; COPD = chronic obstructive pulmonary disease; eGFR = estimated glomerular filtration rate in ml/min/1.73m^2; NYHA = New York heart association.